Vortex Matter Behavior Dependent on Magnetic Field Orientation in Bi2212 Crystals

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Abstract

We have studied Bi2212 crystals that present clear signatures of the 3D-2D decoupling transition of Abrikosov vortices along the crystal **c** axis. The results are consistent with a model for 2D melting transition, where the Josephson coupling between pancake vortices in different planes are suppressed by thermal fluctuations. The angular dependence with the magnetic field orientation was also measured up to H = 7 T, showing that only the field component parallel to the crystal **c** axis is relevant for the 3D-2D decoupling transition.

Layered Superconductors, Decoupling Transition, Vortex Melting, Vortex Matter

1. Introduction

Although vortex matter phase diagrams for the layered superconductor $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi2212) have been extensively studied [1,2], several issues still remain unclear in the literature. Recent works [1,3] have revealed a rich variety of possible vortex regimes, when a tilted magnetic field is applied, involving the interaction between pancakes of Abrikosov vortices (AV) and Josephson vortices (JV). One of the possible behavior of the AV in strongly layered materials is the 3D to 2D decoupling transition, described by different theoretical models [2,4,5] but not yet clearly identified experimentally. In this work we present clear signatures of the 3D-2D decoupling transition, consistent with existing models, and its angular dependence with the magnetic field orientation. We have studied two Bi2212 crystals having critical temperatures T_c^A = 87 K and T_c^B = 89 K, that produced similar results. Only the data for crystal *B* will be shown here. The crystals were grown by conventional self-flux method, with Bi_2O_3 in excess, producing shiny platellets with typical dimensions 1.5×1.0×0.04 mm^3. Crystal *B* was annealed in flow of oxygen at 450 ^oC for ten days, while the other was kept as grown. The magnetic moment M was measured in ZFC and FCC modes, using an SQUID and a sample holder that allows for angular positioning with an error $\Delta\theta = \pm 0.5^o$, where θ is the angle between H and the crystal **c** axis

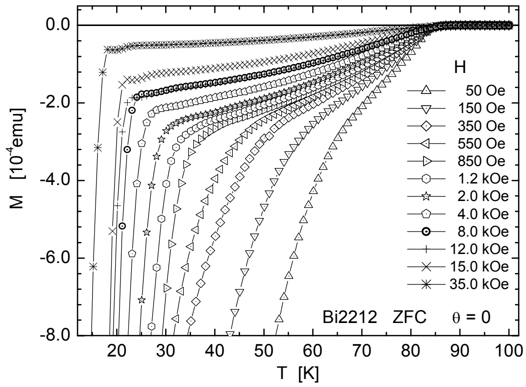

Fig. 1. M×T curves measured under several applied fields, with θ = 0 (only the ZFC parts are shown).

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2. Results and Discussion

Fig. 2 illustrates the effect of tilting the sample by different angles (θ = 10^o, 20^o, 60^o, 80^o and 85^o). This produces broadened transitions with the onsets shifted to higher temperatures. The broadening effect could be due to the fact that our SQUID measurements detect only the longitudinal (vertical) component of the global magnetic moment. Then, for θ > 3^o [3] one should expect a para-magnetic contribution in the measured signal, which arises from the penetration of Josephson vortices between the CuO_2 planes.

Fig. 3 shows the B×T_J phase diagram (B ≈ H), obtained from M×T curves like the ones shown in Fig. 1, for θ = 0, and Fig. 2, for $\theta \neq 0$. For H > 2 kOe the point T_J is sharply defined and for smaller H values this transition region broadens, requiring the use of two auxiliary straight lines to help identify a transition point.

The high field region of the phase diagram for θ = 0 (open circles) can be well described by a theory of 2D vortex melting that predicts, for $B > B_{2D}$ [2,4]:

$$B_m(T) = B_{2D}\exp\left[b\left(\frac{T}{T_{2D}}-1\right)^{-0.37}\right]$$

The dotted line in Fig. 3 represents a fit of this equation to our data, with B_{2D} = 2800 G, T_{2D} = 14 K and b ≈ 1.5 (as expected, of order 1). Since,

$$B_{2D} \approx \frac{\pi\,\Phi_0}{\gamma^2 d^2}\ln\left(\frac{\gamma\, d}{\xi_{ab}}\right) \quad \text{and} \quad T_{2D} \approx \frac{d}{8\pi\sqrt{3}}\left(\frac{\Phi_0}{4\pi\,\lambda_{ab}}\right)^2,$$

where $\gamma = \lambda_c/\lambda_{ab}$ is the anisotropy parameter, d = 15 Σ is the CuO_2 interplane distance, $\xi_{ab} \approx 20\ \Sigma$ and $\Phi_0 = 2.07\times10^{-7}$ Gcm^2 is the flux quantum. From these data we found $\lambda_{ab} \approx 2200\ \Sigma$ (in-plane penetration depth) and $\gamma \approx 230$ (anisotropy), in agreement with typical results for Bi2212.

In the low field region ($B < B_{2D}$) the vortex pancakes are fully coupled, forming 3D flux lines, which are expected to follow a melting line given by [4]:

$$B_m \approx B_0 (T_c - T)^2 / T^2 .$$

The dashed line in Fig. 3 represents a fit of this equation to the data for θ = 0, using T_c = 89 K and B_0 = 500 G. Although this fit seems to describe the B×T_J data for B < B_{2D} one should be cautions about this result, since in this region no clear melting transition points were detected using the global magnetization measurements (see Fig. 1).

The other points measured in H = 70, 60, 35 and 4 kOe, with the sample tilted by the angles θ = 20^o, 60^o, 80^o, are represented by open symbols in Fig. 3. All these points are systematically shifted to higher temperatures. However, plotting the field component parallel to the sample c-axis, H cosθ, the vertical coordinates for the points with $\theta \neq 0$ drop down (solid symbols), coming very close to the result for θ = 0. This means that only the field component perpendicular to the CuO_2 planes is relevant for the 2D melting transition line.

Concluding, we note that a decoupling line similar to that shown in Fig. 3, was also found [5] in transport measurements of the critical current along the **c** axis of Bi2212 crystals.

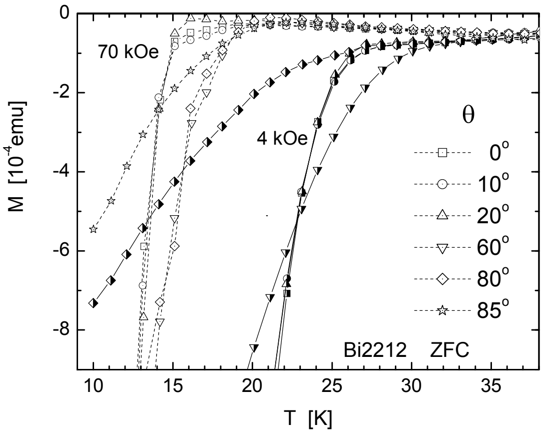

Fig. 2. M×T curves for H = 70 kOe (open symbols) and H = 4 kOe (half-filled symbols), tilted by different angles θ (only the ZFC parts are shown).

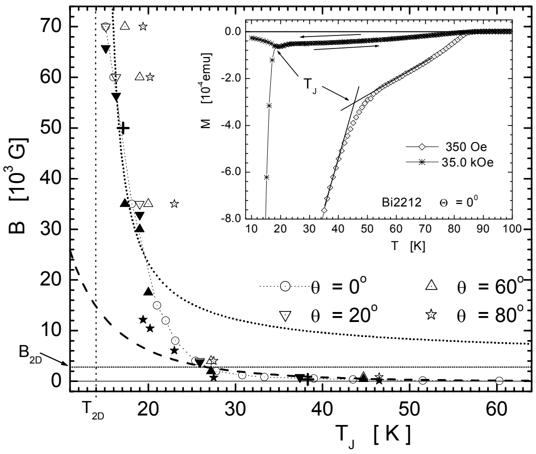

Fig. 3. Open symbols: phase diagram B×T_J (B ≈ H), with data points extracted from the M×T curves. Filled symbols: field component, H cosθ, in the crystal **c** direction. Inset: definition of T_J.

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